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Planning Investments in the Copper Sector in Latin America

The purpose of this chapter is to investigate investment policy in the copper industry in Latin America within a worldwide framework. The copper sector is of high relevance for Latin America for two main reasons:

1. Copper can be counted among its most important nonferrous metals.[1]
2. Peru and Chile are among the most important Third World copper exporters.

The method used is a cost-minimizing multiperiod linear mixed integer programming model of the type described by Kendrick and Stoutjesdijk (1975), which takes into account economies of scale in the investment activities. The model has been extended to consider the notion of declining ore grades. Additional versions of the model consider the impact of tariffs on semimanufactures as well as shipment constraints.

The processes of copper production and fabrication are illustrated in Figure 4-1. These processes range from mining to semimanufacturing

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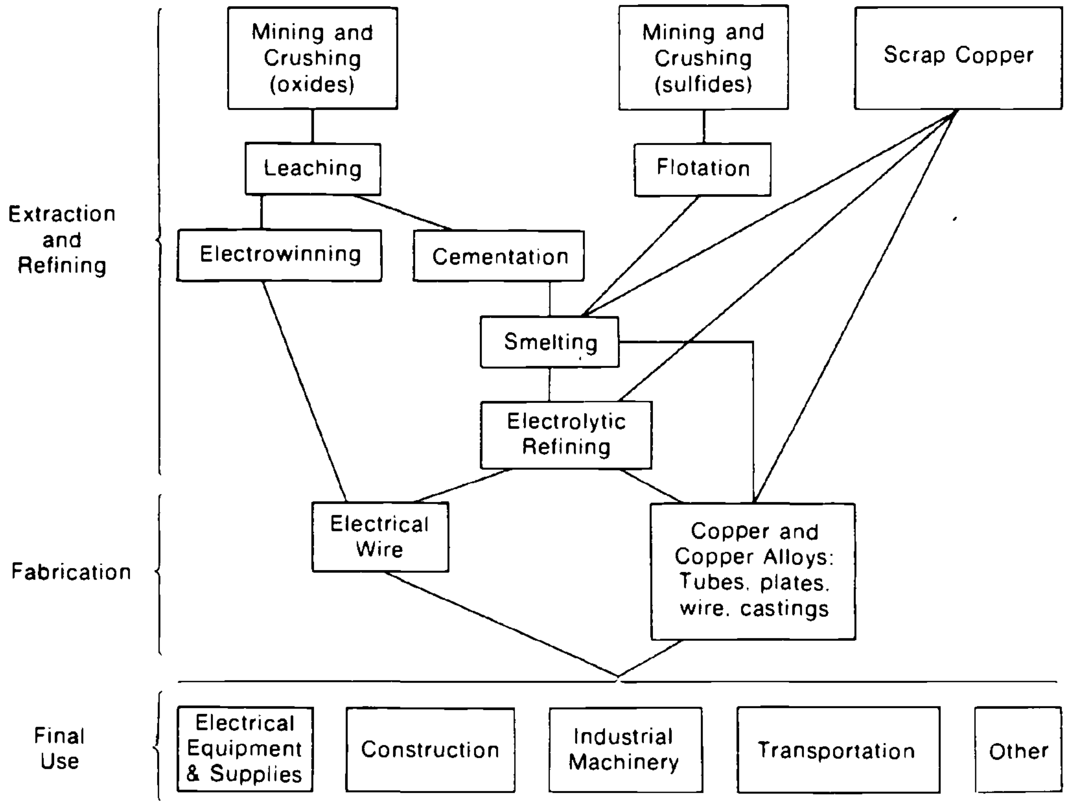

Source: Martijena (1966).

FIGURE 4-1. Process of Copper Refining and Fabrication

and are included in the model. Thirteen producing areas and thirteen market areas are considered. Two time periods are covered: 1975 through 1984 and 1985 through 1994. The solution to the model provides information on investment for timing and location as well as shipments of blister copper, refined copper, and copper semimanufactures. Production levels for each activity are also given by the model but are not presented in this chapter.

Although the model is solved on a worldwide basis, this chapter focuses on its implications for Latin America. A more detailed analysis of the model is presented in Dammert (1977).

DESCRIPTION OF THE MODEL

The model is solved as a mixed integer linear program set to minimize total discounted cost of investment, operation, and transportation over a time horizon, subject to material balance constraints, capacity constraints, investment constraints, and market requirements.[2] This section presents the equations that form the structure of the model. The variables for each equation are described in order of appearance. The plants and markets for the model appear in Table 4–1, 4–2, and 4–5.

The Objective Function

$$\underset{\text{Total Cost}}{\text{Min } \xi} = \sum_{t \in T} \delta_t \left(\phi_{kt} + \phi_{rt} + \phi_{st} + \phi_{k_s t} + \phi_{r_s t} + \phi_{s_s t}\right) \qquad (4\text{–}1)$$

where

$$\phi_{kt} = \sum_{\tau=1}^{t} \sum_{i,m} \sigma_m \left(\underbrace{\alpha_m h_{mit}}_{\text{proportional part of investment cost}} + \underbrace{\beta_m s_{mit}}_{\text{size dependent part of investment cost}}\right) \qquad (4\text{–}1\text{a})$$

$$\phi_{rt} = \underbrace{\sum_{C \in C_r} \sum_{i \in I} \left(p_{dict}\, d_{cit}\right)}_{\text{cost of raw materials}} \qquad (4\text{–}1\text{b})$$

$$d_{cit} = \sum_{p \in P_i} a_{cpit}\, z_{pit}$$

$$\phi_{st} = \sum_{c \in C_f} \underbrace{\left(\sum_{i \in I} \sum_{j \in J} \mu_{cijt} x_{cijt}\right)}_{\text{transport cost of final product}} \qquad (4\text{–}1\text{c})$$

$$+ \underbrace{\sum_{c \in C_{ms}} \sum_{i \in I_p} \sum_{i \in I_s} \left(\mu_{cii't}\, x_{cii't}\right)}_{\text{transport cost of intermediate products}}$$

The variables $\phi_{k_s t}$, $\phi_{r_s t}$ and $\phi_{s_s t}$ are similar to ϕ_{kt}, and ϕ_{rt}, and ϕ_{st} but for the processing of semis.

The description of the variables follows:

ξ = the total discounted cost of production and transportation of copper from mining to distribution of copper semi-manufactures to markets

ϕ_{kt} = total capital cost from mining to refining for year t
ϕ_{rt} = total recurrent cost for mining to refining in year t
ϕ_{st} = total transport cost for mining to refining in year t
ϕ_{kst} = total capital cost for semimanufactures for year t
ϕ_{rst} = total recurrent cost for semimanufactures for year t
ϕ_{sst} = total transportation cost (including tariffs) for semimanufactures for year t
x_{cijt} = shipments of product c from producing region i to market j at time t
$x_{cii't}$ = shipments of product c from plant i to be used as an intermediate product at plant i' at time t
z_{pit} = process level (production level) for production process p at plant i and time t expressed in units of copper content
h_{mit} = continuous investment decision for productive unit m at plant i during time t
s_{mit} = $\{\bar{h}_{mit} - h_{mit}$ for $\bar{h}_{mit} \geqslant h_{mit}\}$
o otherwise
= difference in capacity between the minimum size plant h_{mit} where economies of scale are no longer operative and the plant size h_{mit} being constructed. s_{mit} becomes 0 when actual plant to be built is larger than $\bar{h}_{mit}$

The parameters for Equations 4–1a through 4–1c are:

σ_m = capital recovery factor for productive unit m
$$\sigma_m = \frac{p\,(1+p)^{z_m}}{(1+p)^{z_m} - 1}$$
z_m = life of productive unit m
α_{mi} = proportional part of investment cost
β_m = part of investment cost that depends on plant size
$\bar{h}_m$ = limits of economies of scale for productive unit m
$\bar{h}_m$ = upper bound on capacity expansion in a single period in productive unit m
δ_t = discount factor that transforms costs from time period t to present value according to
$$\delta_t = \sum^{\theta} (1 + \rho)^{-\theta(t-1)-\gamma}$$
γ = 1
θ = number of time intervals per time period
ρ = discount rate
p_{cpit} = recurrent costs to produce commodity c, that is, the domestic cost of raw materials and labor, net of the revenue of by-products

μ_{cijt} = unit transportation cost from plant i to market j
$\mu_{cii't}$ = unit transportation cost from primary to secondary producer

Material Balance Constraints

Final Products

$$\sum_{p \epsilon P_i} a_{cpit} \, z_{pit} \geqslant \sum_{j \epsilon J} x_{cijt} \qquad \begin{matrix} c \epsilon C_f, \\ i \epsilon I \\ t \epsilon T \end{matrix} \tag{4-2}$$

$$\begin{bmatrix}\text{output of} \\ \text{final products}\end{bmatrix} \geqslant \begin{bmatrix}\text{shipments of} \\ \text{final products}\end{bmatrix}$$

Intermediate Products Shipped

$$\sum_{p \epsilon P_i} a_{cpit} z_{pit} \geqslant \sum_{i' \epsilon I_s} x_{cii't} \qquad \begin{matrix} i \epsilon I_p \\ c \epsilon C_{ms} \\ t \epsilon T \end{matrix} \tag{4-3a}$$

$$\begin{bmatrix}\text{output of intermediate} \\ \text{products at plant } i\end{bmatrix} \geqslant \begin{bmatrix}\text{shipment of inter-} \\ \text{mediate products} \\ \text{to plant } i'\end{bmatrix}$$

$$\sum_{p \epsilon P_i} a_{cpit} z_{pit} + \sum_{i' \epsilon I_p} x_{ci'it} \geqslant 0 \qquad \begin{matrix} i \epsilon I \\ c \epsilon C_s \\ t \epsilon T \end{matrix} \tag{4-3b}$$

$$\begin{bmatrix}\text{output of intermediate} \\ \text{products at plant } i\end{bmatrix} + \begin{bmatrix}\text{shipment of intermediate} \\ \text{products from plant } i' \\ \text{to plant } i\end{bmatrix} \geqslant 0$$

where a_{cpit} = process inputs ($-$) or outputs ($+$) per unit of activity level z_{pit}

Equation 4–2 states that the output of final product c at plant i must be greater than or equal to shipments of commodity c to all markets j. Equation 4–3a relates the output of intermediate products at plant i to satisfy shipments of such products to other plants. Similarly, Equation 4–3b indicates that intermediate products produced at plant i plus intermediate products shipped from other plants must be enough to satisfy the input requirements for the next production stage at plant i.

I_p refers to plants that process only primary copper, while I_s refers to plants that process both primary and secondary (scrap) copper.

Capacity Constraints

$$\sum_{p \epsilon P_i} b_{mpti}\, z_{pit} \geqslant k_{mi} + \sum_{t \epsilon T} h_{mit} \qquad \begin{matrix} m \epsilon M_i \\ i \epsilon I \\ t \epsilon T \end{matrix} \tag{4-4}$$

where k_{mi} = initial capacity for productive unit m and parameter b_{mp} = units of capacity used on productive unit m per unit of output of process p. That is, the activity at each productive unit is limited by initial capacity plus later additions to capacity from new investments.

Investment Constraints

$$h_{mit} \geqslant \tilde{h}_m y_{mit} - s_{mit} \qquad \begin{matrix} m \epsilon M_i \\ i \epsilon I \\ t \epsilon T \end{matrix} \tag{4-5}$$

$$h_{mit} \leqslant \tilde{h}_m y_{mit} \qquad \begin{matrix} m \epsilon M_i \\ i \epsilon I \\ t \epsilon T \end{matrix} \tag{4-6}$$

where $y_{mit} = 0$ or 1 (4-7)

Note that $s_{mit} = 0$ if $h_{mit} \geqslant \tilde{h}_m$

$s_{mit} = \tilde{h}_m - h_{mit}$ if $h_{mit} \geqslant \tilde{h}_m$

where y_{mit} = zero one investment decisions where zero means do not build a productive unit at plant i at time t and one means the decision to build such productive unit

Market Requirements

$$\sum_{i \epsilon I} x_{c'ii't} \geqslant \sum_{c \epsilon C_t} a_{cpi't} z_{pit} + r_{c'i't} \tag{4-8}$$

(shipments from i to i') $\quad \begin{matrix} c' \epsilon RE \\ i' \epsilon I' \\ t \epsilon T \end{matrix}$

This equation requires that shipments of refined copper from producing region i to producing i' must satisfy input demands of refined copper for production of semis plus demand of refined copper for other purposes. The description of the variables that appear in Equation 4–8 is as follows:

$x_{cii't}$ = shipments of product c from plant i to be used as an intermediate product at plant i' at time t

z_{pit} = process level for production process p at plant i and time t expressed in units of copper content

and the parameter

$r_{c'i't}$ = market requirements for refined copper for uses other than semimanufactures of wire, tubes and rods, and sheet, plate, and strip

In addition, the following equations of market requirements for semis are included:

$$\sum_{j \in J} x_{cjj't} \geq r_{cj't} \qquad c \epsilon C_f \quad j' \epsilon J \quad t \epsilon T \tag{4–9}$$

$$\begin{bmatrix} \text{shipments of } c \\ \text{from } j \text{ to } j' \end{bmatrix} \geq \begin{bmatrix} \text{market} \\ \text{requirement} \end{bmatrix}$$

where $x_{cjj't}$ = shipments of product c (wire, tubes or sheet) from producing region j to market j' at time t

Constraints on Processing Different Ore Grades

$$z_{pit} \leq g_{cpit} \qquad p \epsilon OM, OM2 \tag{4–10}$$

This constraint places an upper limit on the annual exploitation of high-grade ores and of second-grade ores where

g_{cpit} = annual availability of ore grade c

$$\sum_{t \epsilon T} 10 z_{pit} \leq v_{pi} \qquad p \epsilon OM, OM2, OM3 \quad i \epsilon I \tag{4–11}$$

Equation 4–11 places an upper limit on total availability of each ore grade. The coefficient 10 relates the activities z_{pit} expressed in annual values to the time periods that represent 10 years each where:

v_{pi} = total reserves of ore grade in processing area i

The equation is included in the model in order to consider the limitation on reserves over the time horizon being covered. Equations 4–10 and 4–11 represent alternative specifications. However, for the lower ore grades only Equation 4–11 is used since actual reserves of such grade are less well covered because of their present subeconomic status, and therefore they may be underestimated.

Shipment Constraints on the Third and Fourth Versions

$$x_{cjj't} - t_{cjj't} \qquad \begin{array}{l} c \epsilon C_f \\ j' \epsilon J \\ t \epsilon T \end{array} \tag{4–12}$$

Nonnegativity Constraints

For all variables.

Owing to the size of the model and the difficulties of obtaining more detailed data, only the main production processes were considered. These processes are: (1) open pit mining and concentration of high-, medium-, and low-quality ore, (2) underground mining and concentration, (3) smelting, refining, and wire semimanufacturing, (4) tubes and rods semimanufacturing, and (5) sheets, plate, and strip semimanufacturing. Scrap processing was considered at the smelting, refining, and semimanufacturing stages. As mentioned earlier two time periods were considered, 1975 through 1984 and 1985 through 1994. Thus the planning horizon covered is twenty years.

The main characteristics of the model are the economies of scale in the investment activities that give rise to the need for a zero-one variables, that is, the mixed integer part of the model and the declining ore grades of the available reserves. Different versions of the model were considered. The first version was the least cost solution without tariffs. The second version included tariffs on semimanufactures in order to consider the actual situation. Finally, a third and fourth version included both tariffs in semimanufactures and lower bounds on shipment activities in order to determine the effect that decisions by less industrialized copper-producing countries would have of selling a certain amount of their copper in the form of semimanufactures. The third and fourth versions differ between each other only in the number of plants considered in some regions. This is important because it shows the difference in costs when a group of countries agree upon building a single plant to serve the region instead of building one plant in each country.

DATA UTILIZED

Forecasts of the demand for semimanufactures were obtained from econometric estimates constructed for such purpose. Details of the methodology of estimation are given in Dammert (1977). The results are presented in Table 4-1. The investment costs associated with mines and concentrators, smelters, and refineries are given in Table 4-2. The data for mines and concentrators is for the higher ore grades. Table 4-3 presents the investment costs for copper semimanufacturing plants.

The operating costs for mines to refineries were estimated from

Table 4-1. Market Demand for Semimanufactures (Thousands of Metric Tons)

				Other		
Countries	*Wire*	*Tubes and Rods*	*Sheet Strip and Plate*	*From Refined Copper*	*From Scrap*	*Total*
1980						
United States	2367	571	694	154	295	4081
Mexico	89	21	12	9	—	131
Eastern South America	224	53	30	22	—	329
Western South America	58	14	8	5	—	85
Western Europe	2272	1305	580	362	316	5835
Soviet Union and Eastern Europe	1145	528	330	198	—	2201
Central Africa	30	13	14	3	—	60
South Africa	46	20	21	5	—	92
Asia	176	60	43	5	—	284
Japan and S. Korea	1207	428	253	17	42	1947
China and N. Korea	327	111	79	11	—	528
Australia	80	19	23	16	—	138
Canada	164	40	48	14	17	283
1990						
United States	3225	779	945	229	383	5561
Mexico	169	40	22	17	—	248
Eastern South America	423	100	56	43	—	622
Western South America	109	26	14	11	—	160
Western Europe	3210	1844	819	545	411	6869
Soviet Union and Eastern Europe	1832	846	528	317	—	3523
Central Africa	57	25	26	6	—	114
South Africa	87	38	40	9	—	174
Asia	334	113	81	10	—	538
Japan and S. Korea	1968	698	413	41	55	3175
China and N. Korea	619	210	150	20	—	999
Australia	96	23	28	19	—	166
Canada	208	50	61	18	22	359

Table 4–2. Investment Costs (Millions of U.S. Dollars of 1974 per Thousand Metric Tons)

	Mines and Concentrators			*Smelters*			*Refineries*		
Productive Unit	*Fixed Cost*[a]	*Variable Cost*[a]	*Maximum Size For Economies of Scale*	*Fixed Cost*	*Variable Cost*	*Maximum Size For Economies of Scale*	*Fixed Cost*	*Variable Cost*	*Maximum Size For Economies of Scale*
Region									
Peru	20	2.8	100	25	1.083	150	2.8	.501	150
Chile	20	2.8	100	25	1.083	150	2.8	.501	150
Zambia	60	2.9	380	25	1.083	150	2.8	.501	150
Zaire	60	2.9	380	25	1.083	150	2.8	.501	150
Mexico	20	2.8	100	25	1.083	150	2.8	.501	150
South Africa	20	2.8	100	25	1.083	150	2.8	.501	150
U.S. West	20	2.53	75	20	.916	150	2.0	.287	150
Canada	20	2.53	75	20	.916	150	2.0	.287	150
Soviet Union and Eastern Europe	20	2.53	75	20	.916	150	2.0	.287	150
Australia	20	2.53	75	20	.916	150	2.0	.287	150
Western Europe	14	3.74	50	20	.916	150	2.0	.287	150
Japan	14	3.74	50	20	.916	150	2.0	.287	150
U.S. East	14	3.74	50	20	.916	150	2.0	.287	150

Source: Computed from Bennett et al. (1973), and from *Engineering and Mining Journal* (1976).

[a]Investment Cost = fixed cost plus variable cost × capacity up to maximum size for economies of scale. Beyond the range for economies of scale it is computed as average cost × capacity.

Table 4–3. Investment Costs for Copper Semimanufacturing Plants (Millions of U.S. Dollars of 1974 per Thousand Metric Tons)

Plants	*Variable Cost*[c]	*Fixed Cost*[c]	*Size after which no Economies of Scale*
Plants for Electrical Wire			
— Industrial Regions[a]	.86	1.69	20
— Less Industrialized Regions[b]	.92	1.80	20
Plants for Tubes and Rods			
— Industrial Regions[a]	0.47	2.82	30
— Less Industrialized Regions[b]	.50	3.0	30
Plants for Sheet, Plate and Strip			
— Industrial Regions[a]	0.67	4.32	30
— Less Industrialized Regions[b]	.72	4.60	30

Source: Martijena (1966).

[a]United States, Western Europe, Soviet Union and Eastern Europe, Japan-Korea, Australia and New Zealand, Canada.

[b]Mexico, Eastern South America, Western South America, Central Africa, South Africa, Asia, China.

[c]See footnote to Table 4–2.

individual country reports and from unpublished sources. For semimanufactures, these costs were estimated using as a basis cost data from Martijena (1966) and adapted for differences in wages across regions. Tables 4–4 and 4–5 summarize operating costs for mines to refineries and for semimanufactures, respectively.

An important feature of the model is that it includes the concept of declining ore grades. Thus constraints on reserves for each region and

Table 4–4. Operating Costs (U.S. Dollars of 1974 per Metric Ton of Copper Content)

Countries	*Open Pit Mines and Concentrators*	*Smelting*	*General for Mining To Smelting*	*Refining*	*Total*
Peru[a]	385.2	141.8	92.8	68.0	687.8
Chile	398.2	174.6	279.4	99.5	951.7
Zambia	365.9	101.6	132.0	31.5	631.0
Zaire	286.2	121.0	136.4	38.0	581.6
U.S. West[b]	425.2	107.9	44.0	74.9	652.0

Sources: Bennett et al. (1973) and from talks with World Bank officials.

[a]Used also for Mexico, South Africa.

[b]Estimates used for all industrial countries but scaled for copper grades.

Table 4–5. Recurrent or Operating Costs, Excluding Copper (Thousands of U.S. Dollars per Metric Ton, 1974)

Countries	*Wire*	*Tubes and Rods*	*Sheet, Place, and Strip*
United States	0.875	0.924	1.223
Mexico	0.564	0.822	1.065
Eastern South America	0.564	0.822	1.065
Western South America	0.564	0.822	1.065
Europe	0.641	0.848	1.105
Soviet Union and Eastern Europe	0.563	0.822	1.065
Central Africa	0.517	0.807	1.042
South Africa	0.517	0.807	1.042
Asia (excluding Japan, Korea, China and North Korea	0.478	0.794	1.022
Japan and South Korea	0.721	0.825	1.147
China and North Korea	0.478	0.794	1.022
Australia and New Zealand	0.579	0.827	1.073
Canada	0.848	0.915	1.210

Source: Estimated from Martijena (1966).

ore grade were considered. The total availability on reserves is presented in Table 4–6.

The availability of scrap to be processed at smelters, refineries, and tubes, sheet, and other semimanufactures was projected from data for 1973 from Metalgesellschaft's *Metal Statistics*. Actual plant capacity estimates were necessary in order to determine investments necessary for capacity expansion. These data are not presented in this chapter.

Table 4–6. Reserve Availability (Thousands of Metric Tons)

Countries	*Higher Ore Grade*	*Medium Ore Grade*	*Low Ore Grade*
Peru	23,500	3,000	6,000
Chile—Open Pit Underground	45,900	6,000	14,000
	9,100	—	—
Zambia	26,000	4,000	6,000
Zaire	18,000	3,000	4,000
Mexico	20,000	2,000	5,000
South Africa	6,000	1,000	2,000
United States—Open Pit Underground	64,600	9,000	19,200
	7,200	—	—
Canada	30,000	4,000	6,000
Soviet Union—Open Pit Underground	27.300	6,000	11,000
	10.700	—	—
Australia	13,000	1,000	4,000
Western Europe	17,000	5,000	—
Japan	25,000	5,000	—
United States East	3,200	800	—

Source: Computed from Banks (1974).

For transportation, the model considers shipments of blister copper (produced at smelters) from less industrialized (Peru, Chile, Zambia, Zaire, Mexico, and South Africa) to industrialized areas (western United States, Canada, Soviet Union, Western Europe, Japan, and eastern United States) and of refined copper and copper semimanufactures between all regions. The modes of transportation included in the model are by ocean and by railroad. The costs were estimated as directly proportional to the shipping distance, but they differ for ocean and rail transportation and for the type of product. Ocean transport was considered at U.S. $0.005 per metric ton nautical mile for blister and refined copper and at U.S. $0.010 per metric ton nautical mile for semimanufactures. Railroad transportation was estimated at U.S. $0.05 per metric ton scale mile and U.S. $0.10 per metric ton scale mile for blister or refined copper and semimanufactures, respectively.

Tariffs on imports of semimanufactures were considered in version two, version three, and version four where they were included in transportation costs. Table 4–7 shows the data utilized for tariffs.

RESULTS

Versions One and Two

Table 4–8 presents the results of the main cost categories for both versions. These results are accompanied by Table 4–9, which shows

Table 4–7. Tariffs on Copper Semimanufactures

Countries	*Tariff (Percent of Price)*	*Tariff/Metric ton (Thousand of 1974 US$)*
United States	4.5%	.076
Mexico[a]	15	.255
Eastern South America[a]	15	.255
Western South America[a]	15	.255
Western Europe	8	.136
Soviet Union and Eastern Europe[a]	15	.255
Central Africa[a]	15	.255
South Africa[a]	15	.255
Asia (excluding Japan, South Korea, China and North Korea)[a]	15	.255
Japan and South Korea	15	.255
China[a]	15	.255
Australia and New Zealand[a]	15	.255
Canada	7.5	.128

Source: Banks (1974).

[a]For regions that do not have uniform tariffs for all member countries or for centrally planned economies a uniform rate of 15% on price was used. This rate is low compared to those in practice (see Morrison, 1976), but due to lack of more detailed information, it was considered adequate for the model since it protected local industry.

Table 4–8. Results of Versions 1 and 2 Cost Categories (Millions of U.S. Dollars of 1974)

Period Costs	Version 1 (without tariffs)	Version 2 (with tariffs)
Objective Function =	207140.0	211315.1
Time Period 1		
Investment cost	842.8	843.1
Recurrent cost	7082.5	7083.1
Transport cost	207.4	199.2
Investment cost semis	573.9	444.4
Recurrent cost semis	9759.5	10088.1
Transport cost semis	128.9	349.6
Total Cost	20197.3	20601.2
Time Period 2		
Investment cost	3831.2	3831.2
Recurrent cost	12864.1	12864.1
Transport cost	331.4	318.3
Investment cost semis	1268.2	1125.1
Recurrent cost semis	14502.8	15126.3
Transport cost semis	170.6	417.5
Total Cost	35051.4	35766.0

Source: Based on the author's computations.

the investment activities resulting from each version. In Latin America, investments in mines are scheduled for Peru and Mexico for the first time period and for Peru and Chile for the second time period. Main competing investments in other parts of the world are the western part of the United States for the first time period and Zambia, Zaire, Canada, the Soviet Union, and Eastern Europe for the second time period. Smelters in Latin America are scheduled for Peru, Chile, and Mexico only for the first time period. No new refineries are included in the solution for Latin America because of higher infrastructure costs than in industrialized regions.

The models without tariffs and with tariffs differ for Latin America mainly in the size of semimanufacturing plants to be built. Western South America and eastern South America produce mainly for their regional markets. One wire plant seems optimal for western South America for the first time period for the case with tariffs, but three wire plants have optimal feasibility for the second time period. However, only one plant for tubes and one for sheet are included in the solution for 1990 in western South America. Thus economies of scale seem important for this region.

Eastern South America seems to benefit from tariffs, especially for

Table 4–9. Investment Activities for Versions 1 and 2 (Thousands of Metric Tons)

	1980		*1990*	
Countries	*Version 1 (without tariffs)*	*Version 2 (with tariffs)*	*Version 1 (without tariffs)*	*Version 2 (with tariffs)*
Peru				
Open Pit Mines	400	400	306	306
Smelters	604	604		
Chile				
Open Pit Mines			1400	1400
Smelters	1323	1323		
Western South America				
Wire Plant 1	—	5.9	16.9	20
Wire Plant 2	—	—	20	11
Wire Plant 3	—	—	20	20
Total	—	5.9	56.9	51
Tubes Plant 1	—	—	—	11.2
Tubes Plant 2	—	—	11.2	—
Tubes Plant 3	—	—	—	—
Total	—	—	11.2	11.2
Sheet Plant 1	—	—	—	—
Sheet Plant 2	—	—	9.2	—
Sheet Plant 3	—	—	—	6.5
Total	—	—	9.2	6.5
Zambia				
Open Pit Mines	—	—	313.2	313.2
Smelters	—	—	240.1	240.1
Zaire				
Open Pit Mines	—	—	1263.4	1263.4
Smelters	—	—	601.1	601.1
Central Africa				
Wire Plant 1	—	17	20	20
Wire Plant 2	—	—	364.3	7
Total	—	17	384.3	27
Tube Plant 1	7.5	7.5	—	—
Tube Plant 2	7.5	—	20	12
Total	15	7.5	20	12
Sheet Plant 1	—	8.1	—	—
Sheet Plant 2	—	—	20.1	12
Total	—	8.1	20.1	12
South Africa				
Open Pit Mines	—	—	11.0	11
Wire	506	746	—	—
Tubes	—	—	—	8
Sheet	24.5	1	2.4	19
Mexico				
Open Pit Mines	571	571	—	—
Smelters	487	487	—	—
Wire	2099	1773	1417	1039
Tubes	—	3.5	—	19
Sheet	—	3.8	—	10

Table 4–9. continued

Countries	1980 Version 1 (without tariffs)	1980 Version 2 (with tariffs)	1990 Version 1 (without tariffs)	1990 Version 2 (with tariffs)
Eastern South America				
Wire	—	81	—	199
Tubes	19	19	47	47
Sheet	—	11	30	26
U.S. West				
Open Pit Mines	728.9	728.9	—	—
Refineries	615.8	615.8	—	—
U.S. East				
Refineries	—	—	392.4	1434.3
United States				
Wire	—	—	—	—
Tubes	192.9	192.9	213.1	213.1
Sheet	175.8	174.9	239.6	240.6
Canada				
Open Pit Mines	75	75	1808.2	1808.2
Smelters	251	251	804.8	804.8
Refineries	269	269	1586.4	1353.2
Wire	—	—	—	—
Tubes	—	—	5	5
Sheet	—	—	—	—
Western Europe				
Smelters	—	—	52.3	52.3
Wire	—	279	—	938
Tubes	13	6.8	339.2	544.9
Sheet	—	—	108.9	216.2
Soviet Union & Eastern Europe				
Open Pit Mines	—	—	2930	2930
Smelters	—	—	948	948
Refineries	—	—	986	1177
Wire	153	153	1241	687
Tubes	70	70	540	318
Sheet	—	44	360	198
Japan & South Korea				
Open Pit Mines	—	—	386	386
Wire	—	—	—	746
Tube	25.6	25.6	137.9	238
Sheet	—	—	74.3	157
China				
Wire	1317	110	1053	292
Tube	—	19.4	190	117
Sheet	—	26.5	140	71
Other Asia				
Wire	405	109	—	158
Tube	—	37.4	90.4	53
Sheet	30	39.7	47.7	38

Source: Based on the author's computations.

wire plants. Investments in wire fabricating plants increase by about 50 percent since tariffs cut imports of such products from South Africa.

Semimanufactures in both western and eastern South America are mainly for the local markets because the U.S. and Canadian markets are served by Mexico, which has a similar cost structure but lower transportation costs. Main investments in semimanufactures in Mexico are in wire plants. It can be seen from Table 4–9 that investments in wire semimanufactures decrease with tariffs by about 15 percent for 1980 and by about 30 percent for 1990. Although not shown here, the reason for this lower level of investment is that South Africa, owing to tariff protection in Western Europe and eastern South America, diverts its shipments of wire to the United States and Canada, thus reducing shipments of Mexican wire to those regions.

Shipment Constraints in the Case with Tariffs (Versions Three and Four)

The versions with shipment constraints were simulated in order to explore the possibilities for western South America and Central Africa, which are important copper exporting regions, to capture a small fraction of foreign markets for semimanufactures. In order to consider a feasible strategy, it was assumed that South America and Central Africa would capture 6 percent of the Asian market (excluding Japan and China) and 3 percent of the rest of the world's market. This section reports only the results for western South America.

Two versions with shipment constraints were considered. Both versions included the same shipment constraints but differed as to the number of semimanufacturing plants to be built. The reason for having two versions was to evaluate the impact of building large plants versus that of building smaller plants. Version three considered three plants for each line of semimanufactures and for each time period. Version four considered for the first time period three plants for wire but only one plant for tubes and one plant for sheet.

The difference in investment costs between the third and the fourth version seemed significant. The total investment cost for three plants for tube semimanufactures with total capacity of 37.4 thousand metric tons for 1980 is 27.7 million U.S. dollars compared to 22.4 million U.S. dollars if only one plant is built as in the fourth version. Similarly, for sheet semimanufactures, the total investment cost for three plants with total capacity of 25.9 thousand metric tons is 32.1 million U.S. dollars compared to 23.1 million U.S. dollars for one equivalent plant. Thus, building one plant for tube semimanufactures costs 19 percent less and for sheet semimanufactures 28 percent less than building three plants for each product, which would add the same manufacturing capacity.

CONCLUSION

This chapter considers a model for determining investments in copper mining, smelting, refining, and semimanufacturing. Although the discussion has focused on Latin America, it has been necessary to take into consideration worldwide supply and demand because of the international character of the copper market.

It can be claimed that the model handles in an intuitively appropriate way the impact of different factors on the copper market. For example, variation in ore grades has a decisive influence on investments in copper mining. At the other end of the process, labor costs in semimanufactures as well as transportation costs seem to determine the location of these activities. In considering economies of scale, the main effects appear to be at the regional level when determining the number of plants per region.

NOTES

1. *Oxford Economic Atlas of the World* (1972: 44).
2. The computer program employed was the APEX III mixed integer programming system (Control Data Corporation).

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